High tech cognitive and acoustic enrichment for captive elephants

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Abstract

This research investigates the potential for using technology to enable novel sensory and cognitive enrichment activities for captive elephants. It explores the usefulness of applying conceptual frameworks from interaction design and game design to the problem of developing species-specific smart toys that promote natural behaviours and provide stimulation. Taking a *Research through Design* approach, we describe the fieldwork that has informed our design criteria, leading to the creation of an interactive prototype of an acoustic toy that elephants were able to control using interface elements constructed from a range of natural materials.

Keywords: elephant, sensory enrichment, cognitive enrichment, interaction design, digital toys, Research through Design, design technology, Animal-Computer Interaction, game design, embedded technology, control, choice, prototyping, participatory design, aesthetics, acoustic stimulation

Introduction

The research presented here is a qualitative study examining the potential for using technology to support the delivery of novel environmental enrichment experiences for elephants kept in captivity, in order to offer them more control, sensory stimulation and cognitive challenges. Taking a Research through Design approach, we have explored concepts for playful interactive systems that have an acoustic output by developing physical prototypes for elephants and using our experiences in the field to inform and inspire future iterations. We maintain that a playful system is a useful paradigm for exploring interaction design for elephants, because of the opportunities it affords for offering choice and control.

The new field of Animal Computer Interaction (Mancini, 2011) is investigating a range of approaches to the problem of designing user-centred systems for animals and this research into devices for elephants aims to contribute towards the development of a methodological approach for designing smart and playful enrichment for all species. However, this raises an important question – can high tech environmental enrichment ever be appropriate for an undomesticated captive animal, which would never have cause to interact with such a system in the wild? We argue that technology can mitigate some of the limitations imposed by living in a restricted environment (French, Mancini and Sharp, 2016). This idea has already been explored with a variety of species; for example, Kim-McCormack, Smith and Behie (2016) highlight the relevance of digital technology for providing dynamic and flexible enrichment in the context of captive primates, while Kingston-Jones, Buchanan-Smith and Marno (2005) endorse the use of technology to support enrichment for lions.

There are a number of different categories of environmental enrichment, relating to food provision as well as sensory, social, environmental and cognitive experience. Feeding-related enrichment is now common-place in UK zoos. As well as offering a nutritional reward, scattering food and using puzzle feeders stimulates physical activity that exercises the body and poses cognitive challenges that exercise the mind. Additionally, this kind of enrichment is an interesting way to expend time in an enclosed space where there are limited opportunities for stimulation; indeed it well known that many animals prefer to work for their food (known as contra-freeloading - Osborne, 1977; Podelsnik and Jimenez-Gomez, 2016).

However, feeding is only one aspect of a captive animal's life experience, even if it occupies a significant portion of their time. Mills, Dube and Zulch (2012) describe how a captive animal whose basic (physiological, safety-related, social) needs are met will be driven to seek cognitive stimulation and will need novel challenges to overcome. In the wild, an animal has complete autonomy and can make meaningful choices in a complex living environment; in contrast, captive animals lack control over many aspects of their lives, where routines are imposed on them for practical reasons and social dynamics are often compromised by enforced proximity to, or separation from, conspecifics.

Offering environmental control

Welfare experts have endorsed the idea of offering animals more control over aspects of the captive environment (Mills et al, 2012; Young, 2003; Whitham and Wielebnowski, 2013). In particular, Mills et al. (2012) explain why control is important in the context of homeostasis, whereby an animal is driven to respond to changes in its environment in order to reduce stress and maintain an optimal physiological or social condition. The ability to control something is an opportunity to respond to a stimulus, requiring the exertion of both physical and mental skills that animals have evolved to express. As a case in point, Buchanan-Smith and Badihi (2012) explored the idea that having control is enriching in a series of studies with captive marmosets during which some of them were provided with switches they could activate in order to increase the amount of light, and simultaneously the amount of heat, in their cages. A decrease in behaviours used as indicators of reduced welfare, such as the amount of time spent self-scratching and scent-marking, suggested that the animals given controls to use were less stressed.

Several researchers have explored how animals might exercise control by allowing them to make choices in a playful context. One such project was undertaken by Dutch interaction designers in conjunction with pig farmers (Alfrink and Lagerweij, 2012). The team used a computer game to improve farm animal welfare, as part of their "Playing with Pigs" project, aimed at reducing stress in barn-housed pigs. Lights on an interactive wall attracted the pigs' attention and if they followed a light with their snout while a human simultaneously used an iPhone interface to follow the light with a finger, the light would become brighter and make an exciting display. Although such technological interventions are not part of pigs' natural experience, they engaged with the installation quite actively. The Playing with Pigs project claimed to be successful both in entertaining pigs (thus reducing the incidence of tail biting behaviour) and in raising awareness of their existence among the meat-eating public.

The expression of playful behaviour is recognised as a highly positive behaviour in captive animals (Oliveira, Rossi, Silva, Lau and Barreto, 2010). Burghardt's surplus resource theory (2005) claims that four factors need to be present for play to emerge – (i) animals should have sufficient energy; (ii) they must be buffered from stress or danger; (iii) they must be in need of stimulation; (iv) the species lifestyle should be sufficiently complex. Zoo-housed animals tend to meet these factors well, as they are properly fed, kept free from danger, have time to be filled and many are species that would have a complex lifestyle in the wild.

Although it is relatively easy to identify, play is challenging to define because it is fluid and transient with no immediately obvious cause (Bekoff and Byers,1998; Sendova-

Franks and Scott, 2012). None-the-less, researchers (Brown, 2010; Sicart, 2014; Burghardt, 2005) have attempted to characterise play, with the following attributes being commonly agreed: it is autotelic (offers intrinsic reward) and it is apparently non-functional (not directly related to fitness). However, there are a number of possible reasons for play behaviour, with current research favouring the idea that play prepares animals for their future lives by refining the control that the prefrontal cortex has over other parts of the brain, allowing the animal to become more adaptable (Pellis, Pellis and Bell, 2010). Burghardt (2010) suggests that behavioural play is a precursor to mental play and may be an important factor in the evolution of cognitive and social abilities in different species.

Spinka, Newberry and Bekoff (2001) claim that toys are intrinsically cognitively enriching because any novel objects of interest provide animals with opportunities to "train for the unexpected", a skill that would develop naturally in the wild, but which is likely to be under-developed in captivity where the living environment is much simpler and routines are in place. Young (2003) points out that toys have been successfully introduced into animals' enclosures in order to stimulate play behaviour for several years and that particularly "mammal and bird species can benefit from the effects of toys." (p.149) On the other hand, Tarou and Bashaw (2016) propose that enrichment providing extrinsic reinforcement (such as food) is likely to have more long-term success in promoting behavioural change than intrinsically rewarding enrichment (such as toys).

Traditional toys are designed for freeform play, in contrast to games, which have a formal structure and require players to understand and accept a system of rules, a distinction discussed by Callois (1961). It appears that animal play more closely resembles freeform play, which is spontaneous and improvisational, rooted in physical sensation and role-play (Brown, 2010). On the surface, toys might appear to offer fewer opportunities than games for exercising control and choice. However, recent developments have seen a new trend emerging towards “enhanced” toys for captive animals (Wirman, 2014; Westerlaken and Gualeni, 2014; Hirskyj-Douglas and Read, 2014), which include embedded technology and offer a measure of interactivity. The integration of a toy with a formal system imposes some game-like qualities on the experience in that the player needs to understand how the system works in order to be able to play with it, thus providing a cognitive challenge and promoting physical engagement and meaningful choices on the part of the animal. The research presented here specifically explores the challenges associated with the design of such smart toys that open up the possibility for new interactions between animals and systems, offering cognitive and sensory enrichment.

Elephants were the species of choice to be our users on account of their cognitive and social complexity (Poole and Granli, 2008; Plotnik, 2010) and because they are known to be playful, demonstrating loco-motor, object and social play all their lives (Lee and Moss, 2014). These behavioural characteristics imply that elephants might be both capable and willing to engage with a technologically enhanced toy. We argue that there may be welfare benefits for captive elephants (with minimal extended family, limited space and little need to forage) from interventions that give them a measure of control over their environment through engagement with a playful system that offers multisensory feedback. The Elephant Welfare Group (http://www.biaza.org.uk/animal-management/animal-welfare/elephant-welfare-group/), endorses the idea that captive elephants should be provided with substantial enrichment, including toys.

Elephants

In order to begin to design a playful interactive system for an elephant, we needed to understand how elephants typically interact with the world and their conspecifics.

According to Poole and Granli (2008), wild elephants typically range over hundreds of kilometres with their large extended families, spending the majority of their time foraging. To survive, they need to develop good geographical memories, make decisions, take risks and use their trunks to smell the environment, manipulate objects and produce sounds. In addition, they need to develop excellent auditory perception. Elephants' social networks are extensive and complex; their repertoire of vocalisations indicates a sophisticated communication system. They engage in antiphonal calling, a form of communication conducted at low frequencies within the herd for the purpose of maintaining group cohesion (McComb, Reby, Baker, Ross and Sayialel, 2003). The calls are all distinct, providing clues to identity. McComb, Moss, Sayialel and Baker (2000) determined that elephants can recognise up to 100 other elephants in their extended families, building up their knowledge as they grow older and encounter more family members. There is also evidence that elephants are highly aware of other sounds in their environment via their sense of hearing, for example, being able to perceive distant thunder and bees (King, Soltis and Douglas-Hamilton, 2010). Acoustic and physical interactions with other elephants, combined with mirror self recognition (MSR), indicate advanced self-awareness and an associated ability to empathise (Plotnik, 2010).

Elephants pose an interesting challenge from the perspective of interaction design, because they perceive and interact with the world so differently from humans. Their physical characteristics, such as size and weight, impose extreme constraints on the design process. This means that the design of any system requiring an elephant interface needs to address significant challenges relating to their unique cognitive, behavioural and physical characteristics.

Design characteristics

There are two aspects to this work – the conceptual model of the toy itself and the design of the interface. These two aspects are deeply integrated, as the interface serves as a metaphor for the underlying functionality and the sensory feedback from the system is an inherent part of the playability of the toy, providing intrinsic motivation to continue playing. In order to play with a novel system, an animal will need to be able to make choices about what to do and use the necessary controls to achieve its aims. We argue that this presents both an interesting cognitive challenge and has the potential to offer appropriate sensory stimulation.

Since environmental enrichment aims to encourage species-appropriate behaviours across a range of categories, the interactive toy should aim to give the captive elephant an experience that reproduces some features of an experience enjoyed by a wild elephant, or which enables the elephant to practice some of the skills that a wild elephant would naturally deploy. Zoos and wildlife parks currently offer their elephants a wide range of low-tech enrichment, therefore our approach has focused on gaps in elephant experience that are not met using traditional enrichment, with the goal of using technology to offer something new.

Designing “something new” that technology can help to deliver is a distinct challenge in itself. What would an elephant find engaging? In order to tackle this, we needed to probe how an elephant might interact with a system by using a novel interface, and also imagine the kinds of systems that would stimulate interest in an elephant. Useful frameworks for developing games and toys for animals (Pons, Jaen and Catala, 2015; Zamansky and Wirman, 2016; Lawson, Kirman and Linehan, 2016) as well as participatory approaches to the design process (Robinson, Mancini, Van der Linden, Guest and Harris, 2014) have recently been proposed by ACI researchers. The frameworks of Pons et al. and Lawson et al. are largely speculative; the former proposing the future development of an adaptive environment and the latter concerned with thought experiments to gain insights. Zamansky and Wirman take a more practical approach, describing a framework that includes performance and environmental measurement, animal sensors and device outputs.

The work presented here builds on their suggestions by emphasising the value of *Research through Design* and the need to underpin conceptual work with clear design goals relating to the theoretical and physical properties of the system – how it supports its purpose and how it manifests in the environment (Lim, Stolterman and Teneenberg, 2008; Hengeveld, Frens and Deckers, 2016). We have adapted methodologies from interaction design, game design and ACI, using an iterative participatory design approach that involves manufacturing and testing different systems with an elephant. The detailed methodology is discussed in the next section.

Method

This section outlines the methods used as part of our Research through Design approach to the challenge of developing novel high tech enrichment.

Understanding elephants

User-centred (UX) design requires a thorough understanding of the design context (Rogers, Sharp and Preece, 2011). It offers a range of possible approaches to the challenge of designing a novel interactive system, and one of the fundamental principles is to gather user requirements at the start of the design process in order to inform development through successive design iterations with the participation of users and other stakeholders. We gathered requirements in three different ways: by reviewing existing literature about elephants, by conducting ethnographic observations at zoological facilities and by developing and testing prototypes with an elephant.

Concept design and prototyping

In order to motivate potential ideas for enrichment devices, we attempted to identify some of the gaps in experience of captive elephants compared to their wild counterparts. This information provided the basis for subsequent brainstorming and concept development, as we were aiming to design playful systems that would encourage the expression of evolved behaviour patterns (such as those recorded in wild elephants) in the zoo-housed animals.

Concepts that were informed by our investigations were initially formulated as labelled sketches, descriptions and miniature cardboard prototypes. When our ideas reached a usable stage (in terms of both suitability and feasibility), they were shared with keepers and animal behaviour experts. Alexander and Beus-Dukic (2009) remark how "(Requirements) are more often created by collaborative work than casually found." This collaboration –

known as Participatory Design - is described by Muller (2003) as the third space in HCI - where developer and user can work together on fulfilling design expectations.

Yet the most important users in this scenario were the elephants – how could they participate in the design process? Usually, during the prototyping stage of UX Design, it is possible to obtain feedback from the user through self-reporting methods, such as questionnaires and focus groups. This is vital because concept development is an iterative process and feedback directly informs subsequent designs. When working with Valli, in order to elicit her feedback we adopted a method used by Robinson et al (2014), developing a series of 'quick and dirty' physical prototypes and testing them in her enclosure to elicit her responses. This particular form of Participatory Design has been called "bodystorming" (Schleicher, Jones and Kachur, 2010) and its goal is to be able to investigate users with their tools or systems in the context (physical space) in which they will be used. In this way, we were able to explore our design ideas in direct cooperation with the elephant as well as via the mediation of her keepers.

The evaluation of design concepts was an inherent part of the prototyping stage, so that we could make adjustments as elephant feedback was observed, recorded, logged and interpreted. To gauge the elephants' reactions to our interventions, we used a variety of methods: (i) observational data and video recordings that showed how they interacted with a novel interface; (ii) data from the system itself that showed whether the controlling mechanism was effective or not; (iii) the expert opinions of keepers interpreting whether the responses were positive or negative by observing elephant body language.

Additionally, the "making" aspect of the work - constructing real objects - was conducive to gaining useful insights (French et al, 2016). For example, we were able to appreciate the qualities of the materials used in the design and reflect on how these qualities might influence Valli's responses. Several iterations of prototyping with Valli resulted in a template concept for a toy that we were then able to test with other zoo-housed elephants at a different facility.

The fieldwork section describes in detail our journey towards developing an interactive toy.

Fieldwork

Ethnographic study

The fieldwork began with an ethnographic study of four African elephants at Colchester Zoo, undertaken between January and March 2014. Observations carried out within the study revealed some of the playful behaviours of the animals, showed their range of movements and interests during discrete time periods and clarified hierarchies within the herd. Interviews with the Head Elephant keeper were useful for explaining the animal husbandry routines in place and for shedding light on the different characteristics of the animals. This information was supplemented by later observations of a small herd of African elephants at Howletts Wild Animal Park, two African females at Blair Drummond Safari Park, two African males at Noah's Ark Elephant Eden and our main user-tester, an Asian female at Skanda Vale Ashram.

The behaviours observed in captivity were compared with behaviours recorded in communities of wild elephants (from the academic literature), in order to identify experiential gaps. Based on our findings, we identified the following experiences and associated behaviours as having potential for expression via high-tech enrichment (for some groups of elephants), in cases where a natural alternative was not attainable.

1. Acoustic experiences – eg. antiphonal calling, opportunity to identify multiple family members, stimulation at appropriate frequencies.
2. Olfactory experiences – eg. scents of multiple elephants in different physiological states, novel environmental features.
3. Cognitive challenges and the need to adapt – eg. route-planning, foraging in unfamiliar terrain, dealing with conspecifics, exercising control over own

behaviour, making meaningful choices about when and where to eat, drink, bathe, play etc.

4. Social experiences – eg. being able to choose companions, fellowship within a herd, allomothering, play-fighting.
5. Physical exercise – eg. opportunity and motivation to walk for long distances.

Possible enrichment ideas were assessed for feasibility, resulting in a set of concepts that focused on offering cognitive and acoustic enrichment.

Concept and participatory design work

The next stage involved testing a range of interface designs in order to understand what might be feasible for an elephant with regard to using controls. Through the designed objects we constructed in collaboration with elephant keepers, we were able to explore some of the more intriguing aspects of ECI (elephant computer interaction).

Initially, we worked with one female Asian elephant living at Skanda Vale Ashram, and later we were able to work with two African males, housed at Noah's Ark Zoo. We tested a number of prototypes between 2014 and 2016, four of which are the subject of this paper and outlined below.

Participatory Design (PD)1: Sound test.

Our initial participant, Valli, was orphaned at birth and has been living with human companions at Skanda Vale Ashram for over thirty years. Valli does not have the opportunity to communicate with other elephants, so we hypothesized that acoustic enrichment in a lower frequency range than human voice might provide her with some interesting auditory experiences. Advice from representatives of the EWG (Elephant Welfare Group) originally cautioned against playing the sounds of unknown elephants to captive animals, as wild elephants have a negative reaction to the sounds of unknown herds (Soltis, King, Douglas-Hamilton, Vollrath and Savage, 2014). We therefore attempted to explore a range of alternative sounds, starting with synthesised sine waves and progressing to complex musical samples.

We knew that Valli had been exposed to different music styles because her main carers, Brothers Danny and Peter, regularly played bluegrass and rock music through overhead speakers, while the ceremonies that took place at the temples included a lot of percussion and singing. From these experiences, we also knew that Valli had previously showed aversion to drums, so before introducing a device with novel acoustic feedback, we needed to check that this would not provoke a negative reaction.

Procedure. We placed speakers on the balcony above Valli's enclosure and played a range of digital sound effects with varying frequencies, observing her reactions.

Findings. We encountered the practical problem of not being able to hear sounds at the lower end of the spectrum ourselves, and therefore not being sure whether the Skanda Vale speakers were large enough to reproduce samples below 30 Hz.

Valli turned in the direction of the speakers and tilted her head when the samples were first played. She spent more time in this position when sounds were in the 60-80 Hz frequency range. These findings implied that hearing unusual sounds would not cause Valli any anxiety and that we could therefore continue to investigate acoustic feedback in our prototypes.

PD2: Acoustic pipe button.

To offer Valli control of an acoustic experience, we designed some simple pipe buttons. These consisted of three large circular sensors made from plywood and tinfoil, mounted on a wooden base. Three sections of 300mm corrugated plastic drainpipe were mounted over the buttons and set in a frame, so that Valli would have to insert her trunk tip in order to activate them.

Observations of elephants have shown that they often investigate crevices and other small spaces with their trunk tips, possibly to search for something edible, but also simply to explore the environment. For this reason, the capacitance sensors activating the buttons were placed at the end of the length of pipe, hypothesising that Valli would be motivated to feel inside the pipe out of curiosity.

Procedure. Capacitance sensors are activated by proximity of conductive objects (in this case Valli's trunk). No contact or force needs to be applied to the sensor, the advantage being that a trunk tip in the vicinity will activate the sensor and no special movements need to be made by the animal. The disadvantage is that the sensor itself provides no tactile feedback to show it has been activated, (unlike a toggle switch, for example, which changes position). Acoustic feedback was generated by the system - small piezo buzzers producing different tones. The pipe buttons were located behind a browsing hole in the wall of Valli's enclosure, so she could only access them with her trunk tip, and not have the full use of her considerable strength which would have enabled her to easily pull them apart.

At this stage in the project, the keepers had become very engaged with the idea of offering Valli some technology-enabled enrichment and worked with the researcher to modify the pipe button system so that it fitted in the location behind the browsing hole. This meant that the keepers shared ownership of the concept, which fostered our collaboration.

Findings. Valli's keeper initially used food to motivate her to put her trunk into a button (Fig 1). The keeper held a banana on the device side of the wall (invisible to Valli); he also called her name and told her what to do. She then explored the device with her trunk, finding a piece of fruit when she felt inside the pipe. When she had the fruit in her trunk, she withdrew it from the browsing hole to eat, and then pushed her trunk back through again. We observed from the device side as Valli spent several minutes exploring the pipes with her trunk. She withdrew her trunk and came back again five times, even thought there were no more bananas on offer.

From our tests, it was clear that Valli would have no trouble using this kind of button, even though she was not able to see it because it was on the other side of a wall. However, we concluded that she was investigating the device in search of bananas. This might have been compounded by the fact that audio feedback from the buttons was of relatively poor quality and low volume, due to the fact that the buttons were located on the other side of a wall.

PD3: Fence mounted acoustic push button

Based on our findings, our new priorities were to design a robust button with stronger audible and tactile feedback and find a location where Valli could see and touch it without being able to destroy it.

Our subsequent audio tests utilised instrumental samples as outputs (for example, didgeridoo, organ pipes, trombone), reasoning that the timbre would be more interesting than a piezo buzzer.

Procedure. Just beside Valli's enclosure is a balcony with a rail made of steel bars reinforced with a thick wire fence. Judging that Valli would not be able to pull down a device that was mounted here, we constructed a wooden frame containing a heavy duty sewing machine button with a spring-back mechanism (Fig 2) which we hoped would offer feedback in the form of resistance to pressure. When activated, the button triggered the production of a brass audio sample.

While Valli was outside, we mounted the button on the outside of balcony fence using heavy bolts, so that it was inside her enclosure and accessible. When she came in, one of her keepers showed her the button and tried to encourage her to push it (without banana inducement).

Findings. Valli did not push the button. She explored the surface and felt round the edges of the new object with her trunk tip, but seemed reluctant to exert pressure on the pad. Brother Stefan showed her what to do using his hand and the sound sample was played, but this did not make a difference to her behaviour. After multiple attempts to engage her with the button, Valli walked away and started banging the gate.

The sewing machine pedal corresponded to our idea of what a button should be like, but on a larger scale. However, it was clear that the action of pushing small items was not a natural behaviour for Valli. Observations of elephants show that they regularly pull objects towards them (eg. branches). Pushing is reserved for large, heavy objects such as suspended tyres and other elephants, and it is typically expressed as an all-body action, not performed with the tip of the trunk. For this reason, we decided to revert to using hidden sensors, but to emphasise the tactile qualities of the button in order to encourage trunk tip exploration.

PD4: Fence mounted control with acoustic and haptic feedback

Infrared technology is a cheap and simple solution for detecting movement, used in field cameras and often in buildings as part of an automated lighting circuit. Therefore we decided to use IR sensors hidden in the button frames. As the button touch pads were securely constrained within the wooden frames, it was possible to experiment with the materials used for the surface, reasoning that textured surfaces might seem more natural and therefore hold more interest for an elephant than smooth manufactured ones. Therefore we knitted rope into textile button pads. Following this line of thought led to the development of haptic interfaces, implemented with small vibrating motors fixed behind the button pads.

Procedure. These buttons were deployed in a similar manner to the previous ones. A keeper was present on the balcony when Valli entered the enclosure, gesturing to the buttons to attract her attention. When she touched a button, two things happened – the button surface vibrated and a sound was played (brass sample).

Findings. This prototype (Fig 3) was our most successful intervention. Valli was able to interact with the buttons and showed more interest in doing so than with any other device. She spent a few minutes moving her trunk between the different buttons, which offered distinct surfaces and haptic feedback from different vibrating motors.

We wanted Valli to understand that she had activated the controls successfully by offering haptic feedback, but in fact this could have been confused with the system output, which was an audio signal. The keepers' consensus was that the design worked well, while the researcher felt it would be appropriate to disentangle the acoustic output and haptic feedback in a subsequent experiment, as it was not clear which sensation Valli found interesting.

PD5: Fence mounted elephant radio system

This prototype was developed for two African male elephants, Janu and Machanga, housed at Noah's Ark Zoo. The project was a collaboration with Lisa Yon from EWG (Elephant Welfare Group: http://www.biaza.org.uk/animal-management/animal-welfare/elephant-welfare-group/) and Ashley Bryant, one of her students, who helped with the installation. The system comprised two radios with three buttons each, offering a choice of acoustic output, so that the elephants could individually exhibit preference in controlling the sounds. The buttons were based on the previous successful design, but focused on controls triggering single actions (audio output) and omitting haptic feedback.

Procedure. We discussed the project with the elephant keeper at Noah's Ark Zoo and undertook a survey of the enclosure to find suitable locations for the device. We subsequently mounted two sets of radio buttons inside the elephant enclosure while the animals were outside, bolting them to the fence at a height of 2.5m to ensure there was only trunk-tip access (Fig 4). When a button was touched, one of three audio clips was triggered – whalesong, a recording of a friendly elephant call (taken from elephantvoices.org site) and a classical track (Bach's D Minor for 2 violins). The audio choices were based on requests from the EWG, who wanted to test whether sounds that had previously been played to elephants by humans (with no response) would generate more interest when elephants were given control over their expression.

When the system was initially installed, we observed the elephants and left instructions for keepers, showing how to reset the system in case it stopped or looped and how to change batteries.

Findings. When the elephants were released into the enclosure, it was part of a routine feeding and keeper-talk-to-visitors event. The loudspeaker meant that the keeper's voice was the dominant noise in the space at that time. None of the keepers drew attention to the buttons. At first, the elephants walked right past the device and we realised that the buttons were not at eye level. However, the elephants then spotted the device from the other side of the shed and came back to investigate. They reached up and touched different buttons (Fig 5) to activate different sounds. Both elephants had an opportunity to play with the buttons.

Ashley was able to observe the night footage from that evening, which showed the elephants interacting with the buttons again. We subsequently noted that the capacitance sensing was affected by the heavy metal bars in the enclosure and this meant that the system did not work consistently. Also, the batteries needed to be replaced after 24 hours. However, the system was in place for five days in total and not destroyed during that time.

Summary

The findings from the prototypes PD2 – PD5 are collected in Table 1, which identifies the positive and negative aspects of each design, informing subsequent iterations.

The reactions of Valli and the two African elephants, Janu and Machanga, indicated a willingness to engage with novel devices, using trunks to investigate. Our wooden framed hidden sensor button design worked for both sets of elephants as a control mechanism for an acoustic system, and it was robust, portable and flexible enough to be used in different situations. We have begun to explore elephant choice with regard to acoustic stimulation, but there are still many interesting questions to investigate, with regard to interface design, underlying system functionality, quality of auditory output and how to enable elephants to show us their preferences.

Discussion

In this section, we discuss the design choices we have made, based on experience of building physical prototypes and testing them with elephants and their keepers. We consider some of the tensions that are inherent in the concept of interactive environmental enrichment design and identify issues that came to light using our Research through Design approach.

Our initial ethnographic study identified some gaps in the experience of captive elephants that could potentially be filled using enrichment and we used these to motivate the concept designs, so that our interventions would have clear enrichment goals. The challenge was to create an interactive system that motivated elephants to use it and engage with the core dynamic Schell's "game experience", 2008) – one that offered the animal an experience that was missing from its usual repertoire but was similar in nature to an experience enjoyed by its wild counterparts, thereby promoting the expression of some natural behaviours. In particular, we were keen to investigate these questions (adapted from Schell's Lens of Essential Experience, 2008) : What experience do I want the elephant to have? What is essential to that experience? How could a toy capture that essence? How can technology support this goal?

We considered the set of potential missing experiences identified during the fieldwork, when we compared zoo-housed with wild elephant behaviour, and ruled out attempting to offer social or olfactory enrichment. This was because we were not in a position to modify herd size nor have sufficient knowledge of chemical signalling in elephants. With regard to promoting exercise, we felt that this could be enabled for specific muscles (eg. trunk manipulations). Consequently, our initial aim was to develop an acoustic toy – one that encouraged free play rather than a structured game with rules, so that it might have similarities with wild elephant object play, yet still offer the kind of cognitive stimulation associated with understanding a new problem space.

Interface design

In order to develop a working concept for a toy, it was necessary to explore the issues relating to how an elephant might be physically and cognitively able to interact with a system. The physical aspect relates to the design of an object that an elephant can control using its evolved way of interacting with the world. What qualities would make such an interface easily usable for an elephant? The cognitive aspect relates to the design of a system that an elephant can understand. As Krippendorf (1989) points out, “Meaning is a cognitively constructed relationship connecting features of objects and features of their context into a coherent unity.” How can we design an artificial control for a novel system that an elephant will be able to perceive, comprehend and use effectively?

The idea of offering control and the opportunity to make meaningful decisions underpins all our design work. We based our initial prototype (PD2) on research into elephant communication suggesting that modalities for interfacing with an object should focus on tactile, acoustic or chemical properties, rather than relying solely on a visual display. “They live in a world that is largely acoustic and olfactory rather than visual.” (Plotnik and De Waal, 2014) Yet it seems that vision does have a significant part to play in the design – when we changed the location of the devices to the balcony rail and the enclosure bars, the elephants moved directly towards the novel items as soon as they saw them. This highlights how, in order to provide an interactive experience for a different species, it is necessary to consider the modalities that are appropriate for the species and moreover, that any assumptions about the nature of these modalities might need to be verified.

Another recent example of participatory design where valuable insights were gained in the field is the TOUCH project (Wirman, 2014), a touch-screen game interface whose objectives were to provide enrichment for captive orang-utans, raise awareness of their well-being and facilitate cross-species communication (with humans). Wirman attempted to introduce the orang-utans to multimedia ipad apps (2013), but they were much more focused on touching her skin, playing with her hands, pulling cables and doing other physical activities. Although touch screen tablets are physical objects and have tactile qualities, their mode of interaction is primarily visual. The orang-utans' reaction suggests that they might have found strongly dynamic interactions to have more appeal and make more sense for them.

Sensible UX design for an animal would make use of its existing knowledge of the world and simplify the controls so that they are natural to activate. This is an important aspect of interface design known as affordance – the idea that an object offers its user an indication of how to interact with it and sometimes also its functionality through properties that the user can perceive, such as its form (Norman, 1988). Thus we might assume that a branch-like structure would suggest to an elephant that it could be tugged (and moreover that it would offer resistance). In fact, our initial concept designs included such controls (bungee ropes as pulleys), but there were insurmountable difficulties associated with mounting these safety from the roof of the elephant shed.

This highlights one of our major challenges – constructing interfaces that were sufficiently robust to be safe, using materials that could be repurposed or bought relatively cheaply and which were easy to work with using our available equipment.

Our first attempt at an elephant button (PD2) was successful as a physical object and as a possible controller because of its shape, size and texture, which had some intrinsic appeal for Valli, evidenced by the amount of time she spent exploring the surface. The heavy duty plastic drainpipe had been lying around in the Welsh countryside, so it probably held some interesting scents as well, besides residual banana. It was not possible to reproduce the physical aspects of the pipe design in a more accessible location because it would have been too easy for Valli to pull apart, which is why we moved on to a more streamlined design.

The choice of rectangular frames for round or square buttons was based on a need to simplify the design so that it could be manufactured quickly and easily, to facilitate rapid prototyping. Additionally, such a design offered clear affordance for keepers, such that it was easy to explain how it worked, and also allowed us to use hidden sensors that mapped easily to outputs via a microcontroller.

In our subsequent designs (PD3, PD4, PD5) we selected interface materials that we believed might have aesthetic appeal for an elephant, as well as being easier to work with. The sewing machine pedal had a rubber textured surface, while the other fence-mounted buttons pads were either made from wood or hand-crafted textile. We used natural fibres to knit textured surfaces that we anticipated might be interesting to explore and found that Valli reached up to explore these objects voluntarily.

For reasons of safety, Valli's keepers recommended that controls should be placed at trunk tip distance, so they could be easily reached but not destroyed. The tip is used to perform delicate manoeuvres, but the full trunk is packed with muscles and using this appendage, an elephant can topple a tree. At some zoos we visited (when we were looking for collaborative partners), keepers suggested that any device the elephant could reach needed to be made from stainless steel. However, this was not a viable option, both in terms of cost and manufacturing capabilities. Indeed, our experiences show that our elephant testers did not attempt to destroy any of the wooden interfaces, but instead targeted loose fittings such as hosepipes, when they were left unattended. We consider that it is worth emphasising that stainless steel boxes are not a natural part of a wild elephant's environment.

Another important consideration is that the need to make the toy visible to the elephant impacts on the location of the device. As well as animal welfare, zoo priorities include the requirement for natural looking enclosures that offer the public an approximation of the animal's natural habitat. They are typically keen to ensure that their outside enclosures fit this description, which means that novel artificial enrichment may be better placed indoors. In any case, visible wire or other technical equipment is not desirable, as well as being a potential safety hazard. We were fortunate to be able to explore some of the design questions with Valli at Skanda Vale Ashram without needing to develop final products, because the ashram is not a zoo and Valli receives no public visitors. The enabling technology was visible to researchers and keepers, as we regularly made adjustments during the prototyping. Because our focus was on the interface from Valli's perspective, the controls were always presented in a completely safe, elephant-friendly manner.

Locating the system somewhere suitable is a site-specific challenge. Every elephant enclosure we have explored is different and therefore requires a bespoke solution.

We have also begun to appreciate the individual characteristics of elephants themselves, who have different preferences and roles within the hierarchy of their herd, suggesting that any solution could not be "one size fits all". McCormack et al (2016) support this notion with regard to enriching apes, who also exhibit individual characteristics. In other words, we should not expect enrichment to necessarily be identical for different elephants.

Nonetheless, an important aspect of the ethnographic study was also the insight gleaned regarding similarities between members of the same species. Our observations of common features, such as a willingness to be tactile – physical proximity, touching each other with trunks, barging to emphasise superiority or strength, constant exploration using trunk to smell and touch surroundings – informed our interface designs by providing insight both into their experiential manifestation and how they might support interactivity.

Concept development

We made the decision to focus on developing toys with auditory output for a number of reasons. Firstly, acoustic stimulation is an element of sensorial experience and also fundamental for establishing and maintaining social bonds. Captive elephants in small groups do not experience a full range of herd-associated communications; in consequence, our goals in offering acoustic enrichment were to promote both sensory and cognitive behaviours associated with discriminating between different sounds.

Secondly, although using acoustic stimulation as an aspect of environmental enrichment has been attempted with elephants before, in no instances have we found reports of elephants being given control over the audio production, thereby offering them a choice. Wells and Urwin (2008) observed that elephants showed less stereotypic behaviour when they were played "classical music" and anecdotal evidence (http://www.musicforelephants.com/ ; https://www.thedodo.com/elephant-zoo-classical-music-1206110193.html) suggests that some music does have elephant appeal. In these examples, humans have selected and played pieces of audio to elephants; in another case (http://www.stevetorok.com/elephant_music_project/) elephants were given the opportunity to control percussive elements. With this in mind, our aim has been to produce an interactive toy that allows an elephant to make selections about the kinds of sounds being produced.

Finally, audio signals can be produced and altered programmatically, which means that they are a practical form of output for a technically enabled system. Rather than use samples of music, the initial intention was to synthesise some sounds with low frequencies (infrasound), so they had waveforms in common with elephant rumbles. The rationale for this was that while humans appreciate musical harmony, there is minimal evidence of other mammals finding it interesting. Uetake, Hurnik and Johnson (1997) report that "classical music" influenced cows in a positive manner prior to milking, but Ritvo and Macdonald (2016) discovered no benefits for orang-utans subjected to "music", nor did Wells, Coleman and Challis (2006) note a significant effect of "classical music" on zoo-housed gorillas. On the other hand, dolphins have demonstrated the ability to learn new acoustic signals that resemble sounds made by their own species (Herzing, Delfour and Pack, 2012), while Snowden, Teie and Savage (2015) report that cats prefer "species-appropriate" music, based on sounds they hear in infancy.

During our fieldwork with Valli, we experimented with various auditory outputs, including a range of low frequency sine waves, as well as samples from wind/brass instruments with a long bore on the grounds that the harmonics might have something in common with noises generated by a trunk (Gilbert, Dalmont and Potier, 2010).

Sourcing the requested sounds for the elephant radio ("classical music", whalesong, elephant call) was an interesting challenge. Classical music is a broad category, including many different types of sounds. Research surprisingly did not reveal which tracks had been deployed in previous studies of playing music to animals, as if the nature of the music was of little consequence. To inform our choice, we investigated anecdotal and video evidence of elephants apparently showing pleasure at the sound of classical music, notable in that it was always in an acoustic setting, not emanating from speakers.

Recordings of whales and elephants can be found on the Internet. With regard to elephants, it is known that their calls are context dependent and have meaning for other members of the herd. The Elephant Voices Organisation (https://www.elephantvoices.org/) has collected and categorised a wide range of elephant calls, providing information about each one to explain if it is a distress call, for example, or a request for play. For our purpose, we selected a "rumble-coo" noise, made by a mother to soothe her calf, as we wanted to ensure that the call had a positive association. Unfortunately, no such database of whale songs yet exists, although it seems likely that these calls also have meanings for other members of the species. We do not know the context of the whale song we used.

Research through Design with an elephant

Although Valli always explored the physical aspect of our devices, she showed little engagement with any of the sounds we proposed to her. However, a note-worthy observation from our fieldwork was the level of interest she demonstrated when she encountered the vibro-tactile button pads. Tiny ERM (eccentric rotating mass) motors produce a low volume sound wave when they vibrate, so they can be perceived aurally as well as felt through mechano-receptors under the skin. This suggests some possible future directions for research. Auditory installations might be more interesting for elephants if the technology enabled a range of rotating physical devices that vibrated at different frequencies to produce sounds, rather than using samples of existing human instruments or orchestrations. With a graduated controller, an elephant would be able to alter the rotational speed / frequency at will, thus facilitating the user feedback that is inherent in participatory design.

This highlights one of the fundamental challenges of designing for and with animals – how is it possible to really find out what the animal thinks about the experience? We attempted to do this by offering Valli a range of options, but it was extremely difficult to gauge her responses because of the conflation of the sound effects with other stimuli, such as the presence of strange human researchers, unusual smells emanating from a novel device and the recurring possibility of food rewards.

Martin and Niemitz (2003) found that Asian elephants are typically “right-trunkers” or “left-trunkers”, which adds to the notion that the trunk can be compared in some ways with a human hand – it is used for caressing, feeding oneself and others, investigating novel objects and manipulating tools. The fact that a trunk is also simultaneously a nose and a sound producing organ greatly increases its utility, but also complicates matters when we try to design an interface for an elephant to use to control a system. Foeder, Galloway, Barthel, Moore and Reiss (2011) comment that unsuccessful attempts to demonstrate tool use in elephants may be due to a misplaced emphasis on the trunk as a kind of “hand” for holding a tool, whereas in fact it is primarily a sensory organ in the context of food.

This came to light when we tested our early prototype (PD2), and Valli’s keepers used bananas as enticements because the location of the device meant that it was out of her range of vision. In retrospect we realised this was counter-productive with regard to assessing the viability of the interface design because her focus was on food. When bananas were removed from the situation, the problem was not only that the association had already been made, but also the fact that the residual chemical properties of the banana were easy for an elephant to smell.

There has been a strong assumption from many keepers and welfare experts that food should be the motivator for elephant enrichment because of the large proportion of time that wild elephants spend foraging. However, because an elephant is so motivated by food, using food as an initial motivator means that it then becomes impossible to determine if the animal is performing an action for any other reason apart from the possibility of a food outcome. Food is also strongly associated with training activities, whereas our aim was to design a system that invoked playful behaviour, and play is characterised by being voluntary, not trained (Brown, 2010; Sicart, 2014).

Even without the addition of food as a distraction, it was problematic to assess the effect of individual aspects of the design, because of the integration of so many modalities. Whereas humans can be relied upon to try and separate perceptions into different categories – visual, tactile, acoustic etc – it seems likely that perception is a holistic experience for an animal. Our preparatory work succeeded in collecting qualitative data about elephants' interactions with acoustic toys, but in order to obtain quantitative data in the context of an animal testing an interactive device, there needs to be a clear mapping between a single action on the animal's part to an unambiguous signal delivered by the system. To make that conceptual link, the feedback from the system should be immediate and consistent, as it was when we initially offered the elephant radio to Janu and Machanga at Noah's Ark.

Prototyping in the Noah's Ark environment resolved some questions relating to experimental procedure, but also raised a number of issues that we had not encountered when working with Valli. The keepers at Noah's Ark and the EWG researchers emphasised that novel enrichment should be introduced to the elephants' enclosure and left for the animals to discover independently, in contrast to the keepers at Skanda Vale, who always personally introduced new systems to Valli. The problem with the latter approach is that it may have set up some expectations – Valli might have behaved differently without keepers present; it is possible that she interacted with the buttons in the hope of receiving a food reward or some positive encouragement, since her relationship with her keepers is very personal.

Janu and Machanga, on the other hand, have a PC (protected contact) relationship with their keepers, suggesting that they are less likely to seek approval. In any case, allowing the elephants to investigate novel features in their environment in their own time allowed us to confirm that they would be curious when they first noticed the devices using visual perception. In contrast to Valli, they were both actively engaged with testing buttons for several minutes (until the system failed to work as expected). Future interventions with any group of elephants will use a similar procedure.

Working with Noah's Ark was also productive in that it brought to our notice some of the challenges inherent in designing an acoustic toy to be used by more than one animal.

Social dimensions

Janu and Machanga are usually housed together, but can be separated at night to manage any conflict. Their keepers wanted both elephants to have the opportunity to play with the enrichment, to avoid any competition that might provoke aggressive behaviour or bullying, so we were asked to provide two identical systems. They were placed in two different parts of the elephant shed such that there would be the possibility of having a dividing fence between them. In fact, the elephants were not kept apart during the period of our prototyping, but the fact they both tried to use the system at the same time validated the decision to provide two devices.

However, such a solution is clearly not scalable. In many zoos, elephants are kept in larger groups and it would be impossible to provide individual elephants with their own personal radios. In addition, acoustic output has the property of being pervasive, which means that it would affect all elephants in the vicinity, not only the elephant that used the control. Mancini (2014) highlights this problem in a discussion of smart controls for dog kennels: "For animals housed individually, smart controls seem practical, but for shared housing environments, there are challenges inherent in the design of a system that offers a personalised experience to one animal without imposing their choices on the other animals."

Thus, the provision of interactive acoustic enrichment within elephant enclosures raises many questions. How is it possible to design a system for a group of animals so that environmental control is afforded equally to all the elephants? And is it possible to design a device that enables cooperative rather than competitive play? Sicart (2014) argues that instead of using the term “game designer”, which implies the consideration and construction of a system with pre-formulated objectives, we should use the expression “architect of play” to describe someone who deliberately creates a playful environment – a space that encourages the expression of playful behaviour. We can imagine a playful acoustic environment with multiple controls and multiple outputs – a space rather like Huizinga’s magic circle (1938) that players (elephants) can choose to enter or leave at will; creating such a place depends on available space, consideration of animal husbandry requirements and the willingness of zoo keepers to allow high tech prototypes to be evaluated with their animals.

Conclusions

Our fieldwork has enabled us to explore the design of an interactive toy that offers sensory and cognitive enrichment to captive elephants. We wanted to discover what might motivate an elephant to engage with such a system and what it would be like. By using a Research through Design approach, we have gained valuable insights into a previously unknown problem space.

Determining the ways in which an elephant might be able to interact with a device was approached by reviewing their natural behaviour and understanding how they usually interact with the world, yet designing a suitable toy for an elephant required a leap of imagination. Importantly, the interface design and the toy design were interrelated problems, with the evaluation of one feeding back into the design and development of the other. This symbiotic relationship between concept and implementation has meant that our design interventions have constantly evolved during the research.

We planned to collaborate with both animal carers and the users themselves – elephants – and we therefore attempted participatory design, through iterative prototyping of interactive devices in the elephant enclosure. We started by considering appropriate enrichment goals - what experience to offer the elephant? We then pondered what was essential to that experience, how a toy might be able to capture the essence of the experience (from Schell, 2008) and how to use technology support this goal.

Our designs began to focus on the aesthetic aspects as much as the practicalities – in other words, what an elephant might enjoy interacting with, as well as what was physically possible. We became interested in exploring the sensory qualities of the interface; therefore we developed a prototype button using wood and knitted textiles. Using embedded technology, we tested different kinds of sensors as input devices and various acoustic and haptic signals as outputs, mediated through a micro-controller.

During the process of conducting this fieldwork, we developed working relationships with elephant keepers, facilitated through the shared experience of “making” playful objects for an elephant. We tested different procedures for introducing enrichment devices and we learned about elephant preferences with regard to using controlling mechanisms. We also discovered some possible motivations for future prototypes, such as the idea of developing haptic interfaces. The research has also raised questions relating to sharing devices between groups of animals and the pervasive nature of broadcast audio undermining the idea of providing control to everyone.

Our designs were limited in scope due to a number of species-related constraints and other factors such as time, financial investment and portability. We experienced technical challenges that need to be resolved, including issues of quality and consistency of system output. Our plan is to collect more data from a subsequent elephant radio experiment, demonstrating the frequency of selecting specific tracks. New priorities for Noah’s Ark elephants are to design a more stable system and build two separate versions so that the elephants are not close together when they play, as well as using extra field cameras to capture sounds as well as videos. We then plan to extend the trial to include Valli as a participant, repurposing the buttons to offer her a wider range of acoustic effects. We hope to investigate how to implement a graduated control for analogue input in order to better determine her acoustic preferences, offering her an instrumental toy so she can control pitch and volume.

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Appendix

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Table 1: Comparison of system designs

CONTROL	**SENSOR**	**OUTPUT**	**MATERIALS**	**PROCEDURE**	**LOCATION**	**RESULTS - positive**	**RESULTS - negative**
PD 2 Pipe button	Capacitance sensing (hidden)	Acoustic (sine wave buzz)	Drain pipe – large corrugated cylindrical shape	Keeper collaboration in build. Introduce with banana	Browse hole	Tactile – lots of trunk exploring, control in protected location.	Association with food in location, banana training required.
PD 3 Pedal button	Push-to-make sewing machine pedal	Acoustic (brass sample) + spring mechanism feedback	Wooden frame, repurposed sewing machine pedal	Keeper on balcony directs attention	Balcony rail	Visible, tactile, interest in exploring surface and frame. Good location, firmly bolted at trunk tip height	Valli won't push, no interest in sound (mild aversion).
PD 4 Vibro-tactile buttons	PIR (hidden)	Acoustic (samples) + vibromotor	Wooden frame, knitted rope textile surface + haptic feedback	Keeper on balcony directs attention	Balcony rail	Visible, tactile – lots of trunk exploring vibrating interface, easy to use. Good location, firmly bolted at trunk tip height	No apparent interest in sounds.

PD 5 Elephant radio	Capacitance sensing (hidden)	Acoustic – whale song, classical music, elephant rumble-coo	Wooden frame, copper plate	Leave in place for elephants to find	High on fence	Visible, tactile, interest shown initially from both elephants. All buttons deployed multiple times during different periods of day/night. Good location, firmly bolted at trunk tip height	Technical issues - capacitance interference and batteries run out

Figure 1: PD2 Valli puts trunk through browsing hole in wall to retrieve banana from the pipe button

Figure 2: PD3 Sewing pedal button in wooden frame

Figure 3: PD4 Buttons with tactile and haptic feedback

Figure 4: PD5 Fitting radio buttons to the Noah's Ark elephant enclosure

Figure 5: PD5 Elephants at Noah's Ark playing with the radio buttons